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Controlled-Atmosphere Storage of Apples

R. M. Smock and A. Van Doren

MCINTOSH APPLES IN EXCELLENT CONDITION AFTER REMOVAL FROM CONTROLLED-ATMOSPHERE STORAGE ONE YEAR AFTER DATE OF HARVEST

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CONTROLLED-ATMOSPHERE STORAGE OF APPLES

R. M. Smock and A. Van Doren

Apples can ordinarily be held satisfactorily for rather long periods in ordinary cold storage. There are certain instances, however, where cold storage alone has not proved entirely adequate. For example, McIntosh apples cannot be held in ordinary cold storage with full assurance that they will be of prime eating quality after February or March at the latest. McIntosh frequently develops a cold-storage disorder known as *brown core,* when held for extended periods in ordinary cold storage.

Controlled-atmosphere storage would seem to be a logical supplement to cold storage with this leading variety of New York and New England. The principles of controlled-atmosphere storage[1] were originally developed by Kidd and West (7) in England. This report summarizes four years' work on the applicability of this procedure to McIntosh and for shorter periods on other varieties. Information and data on the actual construction and management of this type of storage are also included.

WHAT IS CONTROLLED ATMOSPHERE STORAGE?

Fruits carry on respiration, a process which is characteristic of all living things. In respiration, sugars are oxidized, or burned, in the presence of oxygen; carbon dioxide, water vapor, and heat are produced as a result of the process. The more rapid the respiration, the more quickly the fruits will deteriorate. The rate of respiration may be reduced by several means. The first means is to lower the temperature. This is the fundamental principle of cold storage. The second means is to reduce the amount of oxygen available to the fruit, since oxygen is required in respiration. The third is to increase the normal amount of carbon dioxide around the fruit. Accumulations of carbon dioxide slow down the chemical reaction involved in respiration. A combination of all three of these principles is involved in controlled-atmosphere storage.

In a gastight room that has just been filled with apples, the atmosphere in the room is ordinary air. Air is composed of about 78 per cent nitrogen, 21 per cent oxygen, 0.03 per cent carbon dioxide, and small percentages of other inert gases. After sealing the room, the constituents of the atmosphere are certain to change in this gastight room. Because of respiration the oxygen is consumed and finally completely exhausted, if the storage operator makes no provision for supplying fresh air. When the normal percentage of oxygen is completely gone, the quantity of carbon dioxide present is approximately 21 per cent, since it is produced in volumes about equal to those of oxygen consumed. If this were allowed to proceed much farther, the fruit would become alcoholic in a very short time. But if when the

[1]There are a number of objections to the term *gas storage,* as the procedure is called by the English. The term *controlled atmosphere* has been substituted, since control of the various constituents of the atmosphere is the predominant feature of this technique. A substitute term or synonym is *modified-atmosphere storage.* A descriptive term adopted by several of the New York storage operators who have used this technique is *modified-air storage. Carbon-dioxide treatments* or *carbon-dioxide storage* are more properly assigned to relatively short period treatments with rather high concentrations of artificially supplied carbon dioxide. These carbon-dioxide treatments seem adapted more to short holding periods in transit or to storage for the stone fruits and some of the small fruits such as raspberries and strawberries.

percentage of oxygen reached 11 per cent, it were maintained at that figure by introducing small amounts of fresh air as required, the carbon dioxide would be 10 per cent. In fact, the percentage of carbon dioxide in this type of storage can be estimated by subtracting the oxygen figure from 21 per cent. The remainder of this atmosphere of 10 per cent carbon dioxide and 11 per cent oxygen is always nitrogen. This atmosphere of 10 per cent carbon dioxide and 11 per cent oxygen, with a temperature of 40°F., is the one most commonly used in England. When the carbon-dioxide indicator shows more than 10 per cent carbon dioxide, the room is ventilated as required to maintain that figure. No attention is paid to the nitrogen fraction.

Suppose a certain variety responds best to a very low oxygen atmosphere, such as 2 per cent, and 5 per cent carbon dioxide. First, respiration will lower the oxygen figure from the normal of 21 per cent within a month or slightly more in a gastight room filled with fruit. When the oxygen figure falls below this amount, small quantities of fresh air are introduced as required. The carbon dioxide cannot be controlled by ventilation in this instance because small introductions of air sufficient to control the carbon dioxide would raise the oxygen percentage higher than desired. For this reason when the carbon-dioxide percentage exceeds 5 per cent the storage atmosphere is passed through an atmospheric washer containing a solution of sodium hydroxide or lye, which removes carbon dioxide. This washing is continued until the carbon dioxide percentage is back to 5 per cent. Control of the atmosphere can be obtained by mere ventilation only when the summation of the carbon dioxide and oxygen percentages equals 21 per cent.

EXPERIMENTAL METHODS

Experiments on variety response and atmospheric requirements were conducted in gastight metal containers having a capacity of two bushels. Commercial trials were conducted in rooms of various sizes described in detail in later sections.

Atmospheres were obtained by supplying the required gases from cylinders of compressed gas, except during the 1937–38 season. The method in that season has been described elsewhere (16). Air was first completely flushed out of the chambers with nitrogen, and carbon dioxide and oxygen were added as required. Daily checks on concentrations of carbon dioxide and oxygen were made, followed by the necessary manipulations of gaseous constituents of the atmosphere. Atmospheres could be controlled to within 1 per cent of the desired value by this procedure.

Shredded oiled paper or oiled-paper wraps were always used unless otherwise indicated.

Uniformly mature fruit was gathered from trees of known treatment (with the exception of Northern Spy and Golden Delicious, for which field treatments were not known), and composite samples were made for each storage treatment.

Ground color was measured by a standard color chart. Pressure was measured by a Magness pressure tester. Soluble solids were determined with a Zeiss refractometer.

After removal from storage at different dates, the fruit was held at room temperature but in a high relative humidity (90-95 per cent). The fruit

was declared unmarketable after it was judged to be past a state in which it could be readily sold on the market. Naturally these high relative humidities would not prevail on the market place. This was done to determine the comparative merits of different treatments with the shriveling factor eliminated.

CONSIDERATION OF THE PROPER TEMPERATURE AND ATMOSPHERE

At temperatures lower than 40°F., carbon-dioxide injury is likely to be a factor, as a preliminary report (18) has shown. In table 1 it is indicated

TABLE 1. EFFECT OF TEMPERATURE ON APPLES STORED IN AN ATMOSPHERE OF 5 PER CENT CARBON DIOXIDE AND 2 PER CENT OXYGEN

Treatment	Date of examination	Firmness lost (pounds)*	Ground color†	Brown core (per cent)	Days marketable‡	Cause of discard
			McIntosh			
36° F.	6/2/39	4.2	2½–3	55	37	Soft, and brown core
40° F.	6/2/39	5.0	2½–3	0	34	Soft
			Cortland			
36° F.	6/2/39	4.5	3	..	4	Scald
40° F.	6/2/39	4.5	3½	..	0	Scald

*Pressure test at examination date subtracted from pressure test at harvest time.
†Expressed in whole numbers as measured by standard ground-color chart.
‡Number of days fruit remained marketable at room temperature and high humidity after removal from storage.

that no better keeping quality in storage is obtained with McIntosh at 36° as compared with 40°. Brown core is more of a problem at 36° than at 40°. There is some indication that this trouble is caused by temperature-and-carbon-dioxide injury, but further study is needed on this point. Van Doren (20) found somewhat lower respiration rates at 36° than at 40° but this was offset by the appearance of brown core. Cortland kept just as well at 40° in this atmosphere as at 36°. As pointed out in a later section, scald was a complicating factor with this variety.

Phillips (12) in Canada recommends a storage temperature of 39°F. in controlled atmosphere, but this is to accompany an atmosphere of 7 per cent carbon dioxide and 14 per cent oxygen. Kidd and West (7) have shown that 40°F. seems to be optimum for most of their varieties in controlled atmosphere. A temperature of 40° seems desirable for the particular atmosphere which is recommended for most New York varieties. A temperature of 36° would give very little if any better results and would be more expensive because of the extra refrigeration required.

A report (18) has already been made on the proper combination of carbon dioxide and oxygen to use with McIntosh and Cortland. An atmosphere of 5 per cent carbon dioxide and 2 per cent oxygen was found to be the best of those tested with the varieties McIntosh and Cortland (18). The question arises, however, as to how much better this atmosphere would be than one that could be maintained by ventilation without an at-

mospheric washer. For example, Phillips (12) recommends a temperature of 39° and an atmosphere of 7 per cent carbon dioxide and 14 per cent oxygen. Up until 1938, at least, only 1 of 200 controlled-atmosphere storages in England used an atmospheric washer commercially. In table 2 it is

TABLE 2. COMPARISON OF CONTROLLED-ATMOSPHERE STORAGE WITH ORDINARY COLD STORAGE OF McINTOSH

Storage treatment	Date examined	Firmness lost (pounds)	Ground color	Brown core (per cent)	Condition	Days marketable	Cause of discard
			1937–38				
Air, 36° F.	4/29/38	4.8	3½–4	20	Poor	0	Soft
5 per cent CO_2 and 2 per cent O_2, 40° F.	4/29/38	4.5	3–3½	0	Good	6+*	.....
10 per cent CO_2 and 11 per cent O_2, 40° F.	4/29/38	6.5	3–3½	0	Fair	0	Soft
			1938–39				
Air, 32° F.	6/2/39	6.3	3	90	Poor	0	Brown core, and soft
5 per cent CO_2 and 2 per cent O_2, 40° F.	6/2/39	5.0	2½–3	0	Good	34	Soft
10 per cent CO_2 and 11 per cent O_2, 40° F.	6/2/39	5.8	3	30	Fair	10	Soft, and brown core
			1939–40				
Air, 32–36° F.	5/1/40	5.8	4	0	Poor	2	Soft
5 per cent CO_2 and 2 per cent O_2, 40° F.	5/1/40	4.9	2½	0	Good	20	Soft
10 per cent CO_2 and 11 per cent O_2, 40° F.	5/1/40	5.4	3	25	Fair	7	Soft
			1940–41				
At harvest	10/7/41	..	3	0	Good	52	Soft
Air, 32–34° F	5/1/41	5.2	3–4	100	Poor	0	Soft, and brown core
5 per cent CO_2 and 2 per cent O_2, 40° F.	5/1/41	2.8	3–4	14	Good	26	Soft

*Held only six days.

indicated just how much better an atmosphere of 5 per cent carbon dioxide and 2 per cent oxygen is than one of 10 per cent carbon dioxide and 11 per cent oxygen at the same temperature. With the latter atmosphere the apples do not keep quite so long as with the former, and brown core is more likely to be a factor even at 40°F. With 7 per cent carbon dioxide, less brown core would be likely to occur than with 10 per cent and this probably accounts for the recommendation of Phillips (12). However, table 2 reveals that the low oxygen atmosphere is considerably better than the high. As long as a storage operator has gone to the trouble of making the room gastight and has bought analysis equipment, it would seem advisable to go to the extra expense of another 3 to 4 cents a bushel each season and use the low oxygen atmosphere. For this reason an atmosphere of 5 per cent carbon dioxide and 2 per cent oxygen at a temperature of 40°F. is recommend-

ed for New York varieties. The atmospheric requirements of varieties other than Cortland and McIntosh have not been fully investigated. Since an atmosphere of 5 per cent carbon dioxide and 2 per cent oxygen seemed admirably suited to McIntosh, it was used for the other varieties tested. It was thought that if any given variety did not respond to this atmosphere, trials would be made in the future to determine if other carbon-dioxide-and-oxygen combinations would be more beneficial.

Van Doren (20) has shown that an atmosphere of 10 per cent carbon dioxide and 2 per cent oxygen reduced the respiration rate of Cortland apples below that of 5 per cent carbon dioxide and 2 per cent oxygen at 40°F. This atmosphere has not been recommended, although it would mean less use of the atmospheric washer, because of brown core. Even with this very low oxygen percentage, brown core begins to appear with 10 per cent carbon dioxide at 40°. One point which needs study is the possibility of using 5 per cent carbon dioxide for the first month or two of storage and then using 10 per cent. It is possible that greatest susceptibility to brown core comes early in the storage life of the fruit. Use of 10 per cent carbon dioxide in the latter months of storage would result in some savings in the use of the atmospheric washer.

VARIETAL RESPONSE

McIntosh

Four year's results with McIntosh have indicated that this variety responds quite markedly to controlled-atmosphere storage. In table 2 it may be seen that the storage life of this variety has been considerably increased by the use of controlled atmospheres. Cold-storage McIntosh apples held at 32°F. are usually past prime eating condition by February or at latest by the last of March. Many of them are sold after this date, but they quickly soften on the market place and are of poor eating quality. Controlled-atmosphere-storage McIntosh have been kept in excellent condition until July. Some controlled-atmosphere McIntosh have been kept in storage for 18 months, and have been removed in a condition as good as that of apples removed from ordinary cold storage after 6 months.

In addition to having a longer storage life, the period of marketability is markedly increased by controlled-atmosphere storage. This is strikingly illustrated in table 2. These periods of marketability are somewhat longer than would be experienced in commercial practice, but it seems safe to say that controlled-atmosphere McIntosh will keep considerably longer on the market place than will cold-storage McIntosh, even though at the time of removal from storage (in February, for example) the latter were as firm as the former. Kidd and West (7) have claimed that controlled-atmosphere apples would keep longer on the market place after several months of storage than they would at harvest time. One year's work with McIntosh at this Station indicate that this does not hold for McIntosh. For example, McIntosh at harvest time remained marketable for 52 days at room temperature and high humidity, whereas they were marketable only 43 days after removal from controlled-atmosphere storage on January 1. There is, however, an outstanding residual effect of the storage treatment on keeping quality of the fruit after removal from storage.

In table 2 it is indicated that storage in an atmosphere of 5 per cent carbon

FIGURE 1. McINTOSH APPLES REMOVED FROM STORAGE MARCH 1, 1941, AND HELD 4 WEEKS AT ROOM TEMPERATURE
Left, 5 per cent carbon dioxide and 2 per cent oxygen at 40°; right, 32° air

dioxide and 2 per cent oxygen at 40°F. will eliminate brown core in most years. Susceptibility to brown core seems to vary somewhat from year to year with different climatic conditions during the growing season. Just what the specific effect of different growing conditions on this trouble is, is not known. It has been pointed out previously (18), and it is apparent to some extent in table 1, that brown core becomes more severe with the higher concentrations of carbon dioxide. It is suggested that this disorder may be a carbon-dioxide–temperature relationship, much like that of brown heart, as suggested by Kidd and West (7). It is possible that at 32° in ordinary cold storage even small percentages of carbon dioxide may induce this trouble, whereas at 40° it may take 10 per cent or more to stimulate it.

NORTHWESTERN GREENING

This variety is subject to a trouble known as *mealy breakdown*. It usually does not keep well in storage because of this type of premature breakdown. Detailed studies on the atmospheric requirements of this variety have

FIGURE 2. NORTHWESTERN GREENING APPLES REMOVED FROM STORAGE JANUARY 12, 1938
Left, ordinary cold storage, 36°F.; right, 5 per cent carbon dioxide and 2 per cent oxygen, 40°F. Note browning of core and beginning of mealy breakdown on apple at left

previously been reported (16). With an atmosphere of 5 per cent carbon dioxide and 2 per cent oxygen at a temperature of 40°F., this variety was kept in excellent condition until May 1, although some mealy breakdown was beginning to appear at that time. The browning around the core, which preceded mealy breakdown in this variety, was previously called brown core (16), but work at the Iowa Station (14) indicates that it was merely the first symptom of the mealy breakdown. No scald was experienced on the particular lot of apples experimented with, although the fruit was still of green ground color in May.

TABLE 3. INFLUENCE OF CONTROLLED-ATMOSPHERE STORAGE ON NORTHWESTERN GREENING

Treatment	Date examined	Firmness lost (pounds)	Ground color	Days marketable	Mealy breakdown (per cent)
Air, 36° F	4/29/38	15.9	2½–3	0	100.0
5 per cent CO_2 and 2 per cent O_2, 40° F	4/29/38	9.3	1½–2½	6+*	17.5

*Held only six days.

TWENTY OUNCE

This variety is no longer widely grown in New York and New England, but considerable difficulty has been experienced in storing it for long periods in cold storage. This study revealed that it was subject to a low-temperature disorder similar in nature to brown core. The sample from cold storage at 40°F. was removed in late March in somewhat better condition than that of the sample stored at 32–36° (table 4). This was due primarily

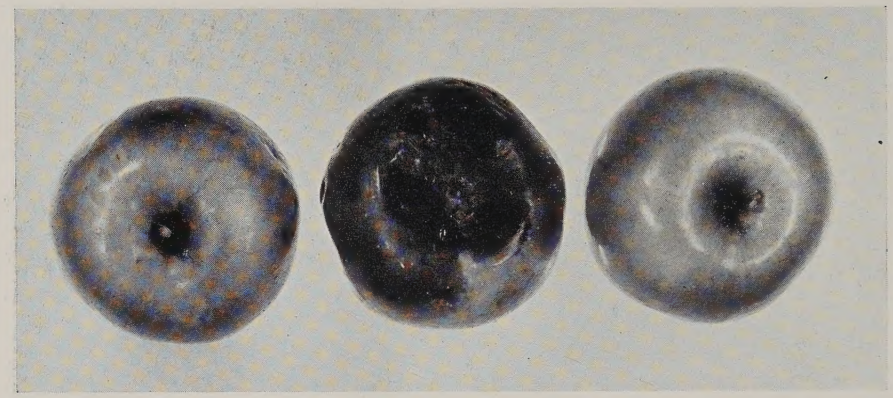

FIGURE 3. TWENTY OUNCE APPLES REMOVED FROM STORAGE MARCH 29, 1940
The apples were then held at 65°F. in high relative humidity for two weeks. Left, ordinary cold storage, 40°F.; center, ordinary cold storage, 32–36°F.; right, 5 per cent carbon dioxide and 2 per cent oxygen, 40°F. This variety is subject to a low-temperature breakdown

to the fact that at the lower temperature the apples were considerably softened by the breakdown on the inside of the fruit. Apples of this variety kept in excellent condition until April when stored in 5 per cent carbon dioxide and 2 per cent oxygen at 40°. A slight amount of scald was noted on this lot after they had been held at room temperature for several days upon removal from storage.

TABLE 4. INFLUENCE OF CONTROLLED-ATMOSPHERE STORAGE ON TWENTY OUNCE

Treatment	Date examined	Firmness lost (pounds)	Ground color	Brown core (per cent)	Days marketable
Air, 32–36° F	3/29/40	8.8	4	100	0
Air, 40° F	3/29/40	8.1	4	30	0
5 per cent CO_2 and 2 per cent O_2, 40° F	3/29/40	6.9	4	0	14

JONATHAN

This variety was stored in an atmosphere of 5 per cent carbon dioxide and 2 per cent oxygen at 40°F. in 1940–41, but it did not respond at all well to controlled atmosphere (table 5). All apples over 2½ inches in diameter were severely affected with flesh browning. The skin looked normal, but the fruits were soft because of the complete browning and breakdown of the flesh on the inside. The trouble was similar to that occurring in Wealthy (figure 4). The browning extended in equal intensity from the core to the skin. The fruit in controlled atmosphere ripened much less than did similar fruit stored in air at the same temperature. Jonathan spot seemed to be controlled perfectly by the use of this atmosphere. It did not develop even when the fruit was held at room temperature for an additional two weeks after removal from storage.

While the severe browning might be a seasonal effect, it would seem that this variety should not be tried commercially in controlled atmospheres.

Further experimental trials with very low carbon dioxide and very low oxygen should be made with this variety. Browning occurred in Jonathan grown in the Hudson Valley and stored in a commercial controlled-atmosphere storage in 1940–41. In some unpublished work the senior author found that Jonathan grown in the Sebastopol district of California developed the same trouble when stored in atmospheres containing carbon dioxide. With 5 per cent carbon dioxide and 15 per cent oxygen at 45°F., Jonathan developed 25 per cent browning. With 10 per cent carbon dioxide and 10 per cent oxygen they developed 90 per cent browning. It would seem that this variety is extremely susceptible to carbon-dioxide injury at even relatively high storage temperatures.

TABLE 5. EFFECT OF CONTROLLED-ATMOSPHERE STORAGE ON THE JONATHAN VARIETY

Treatment	Date examined	Firmness lost (pounds)	Ground color	Soluble solids (per cent)	Jonathan spot (per cent)	Browning (per cent)	Days marketable	Cause of discard
Air, 40° F.	3/6/41	6.5	4	11.8	26.2	0	2	Soft
5 per cent CO_2 and 2 per cent O_2, 40° F.	3/6/41	6.4	3	10.6	0	50.0	0	Browning

WEALTHY

In table 6 are given results obtained with Wealthy in controlled atmosphere at 40°F. in the 1940–41 season. As indicated by firmness lost, ground color, and days of marketability after removal from storage, controlled-atmosphere fruit was somewhat, but not greatly, better than ordinary-cold-storage fruit on January 1. By March 1, brown core had begun to appear in the controlled-atmosphere fruit. It became so noticeable upon removal from storage that the fruit had to be discarded. The brown core in this

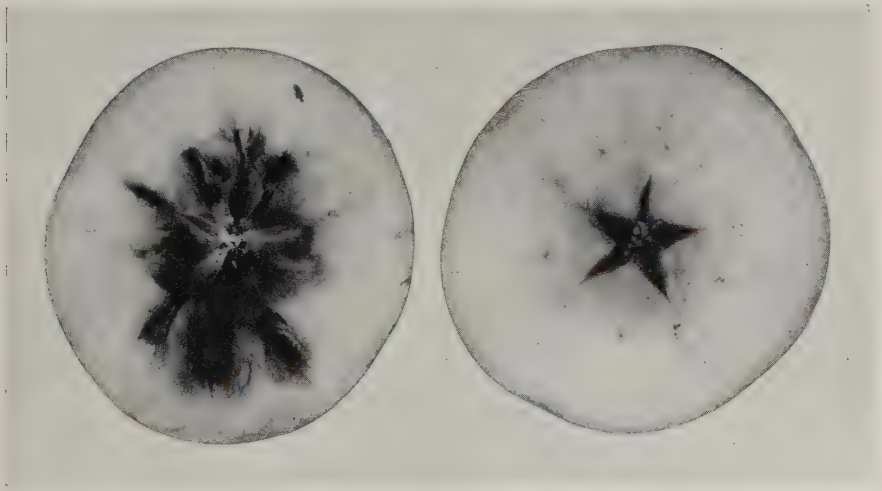

FIGURE 4. WEALTHY REMOVED FROM STORAGE MARCH 7, 1941
Left, 5 per cent carbon dioxide and 2 per cent oxygen, 40°F.; right, ordinary cold storage, 32°F.

variety was of a localized, corky nature. The red pigment seemed to leak out of the skin into the flesh of the controlled-atmosphere lot.

That browning was so apparent in many varieties during the 1940–41 season was undoubtedly a seasonal factor; that is, susceptibility was determined by growing conditions. The fact that brown core was actually worse in controlled atmosphere than in cold storage would indicate that this variety is not adapted to this particular atmospheric combination of carbon dioxide and oxygen. Further experiments will have to be made to determine if this variety will respond favorably to different carbon-dioxide and oxygen combinations. At the present time the variety cannot be recommended for trial in controlled atmospheres.

TABLE 6. EFFECT OF CONTROLLED-ATMOSPHERE STORAGE ON WEALTHY

Treatment	Date examined	Firmness lost (pounds)	Ground color	Soluble solids (per cent)	Days marketable	Brown core (per cent)	Cause of discard
Air, 32° F.	3/1/41	5.6	3–4	10.2	9	0	Soft
5 per cent CO_2, and 2 per cent O_2, 40° F.	3/1/41	4.7	3	11.6	13	73.7	Brown core

BALDWIN

Baldwin apples usually keep very well in ordinary cold storage at 32°F. However, some interest has been expressed among apple growers in the possibility of keeping this variety through the summer months. The question would still remain as to whether Baldwin and similar varieties could be kept through the summer well enough to justify the extra expense of the storage treatment.

Brown core was the determining factor in limiting the length of life of Baldwin in the 1940–41 season (table 7). Controlled atmosphere at 40°F. definitely lengthened the life of the fruit from the standpoint of reduced softening and ground-color change, but brown core was almost as bad as in cold storage. It was a more advanced type of brown core in cold storage, even though the percentage of fruit showing brown core was the same in both storage treatments. Until further trials are made with other atmospheric combinations to avoid brown core, this variety cannot be recommended for commercial trial.

TABLE 7. EFFECT OF CONTROLLED-ATMOSPHERE STORAGE ON BALDWIN

Treatment	Date examined	Firmness lost (pounds)	Ground color	Soluble solids (per cent)	Brown core (per cent)	Days marketable	Cause of discard
Air, 32° F.	3/5/41	8.4	4	13.2	93.7	12	Brown core
5 per cent CO_2 and 2 per cent O_2, 40° F.	3/5/41	4.4	3–3½	14.8	100.0	12	Brown core

RHODE ISLAND GREENING

During the 1939–40 season, scald was so serious on this variety in controlled-atmosphere storage that it was unmarketable upon removal from storage, even though ½ pound of shredded oiled paper per bushel had been

used. From the standpoint of firmness and ground color, this variety remained marketable 27 days after removal from controlled-atmosphere storage in March; it was unmarketable after removing from cold storage, because of softness (table 8).

During the 1940–41 season scald was not a serious factor, since no varieties were as susceptible to this trouble in storage. Scald was controlled by use of shredded oiled paper in 1940–41, whereas it was not in 1939–40. Brown core was very much in evidence during this season (table 8).

Since scald was serious in the 1939–40 season and a minor factor in the 1940–41 season, even when ample supplies of shredded oiled paper were used, and since brown core was present during the 1940–41 season, this variety is not recommended for commercial trial in controlled atmosphere at present.

TABLE 8. EFFECT OF CONTROLLED-ATMOSPHERE STORAGE ON RHODE ISLAND GREENING

Treatment	Date examined	Firmness lost (pounds)	Ground color	Scald (per cent)	Scald after 7 days* (per cent)	Brown core (per cent)	Days marketable	Cause of discard
Air, 34–36° F.	3/29/40	10.2	3	100	100	0	0	Soft
5 per cent CO_2 and 2 per cent O_2, 40° F.	3/29/40	8.4	2–2½	100	100	0	0	Scald
Air, 32–34° F.	3/1/41	12.0	2–2½	0	0	100	13	Soft, brown core
5 per cent CO_2 and 2 per cent O_2, 40° F.	3/1/41	13.3	2–2½	0	11.4	100	12	Soft, brown core

*Seven days at room temperature after removal from storage.

CORTLAND

It has been reported previously (18) that Cortland responded almost as markedly as did McIntosh to controlled atmospheres, but its applicability to this technique was limited by its susceptibility to scald. In table 9 it is indicated that scald was the factor in 1938–39 which limited the usefulness of controlled-atmosphere storage for this variety. During the 1940–41 season, susceptibility to scald was not a serious factor; no scald occurred on Cortland apples in controlled atmospheres where precautions against this trouble had been taken. Data for this season are not presented, since the fruit was held in an atmosphere of 5 per cent carbon dioxide and 10 per cent oxygen at 40°F. It may be safely said that Cortland during this particular year responded just as well as did McIntosh to controlled-atmosphere storage.

TABLE 9. EFFECT OF CONTROLLED-ATMOSPHERE STORAGE ON THE CORTLAND VARIETY

Treatment	Date examined	Firmness lost (pounds)	Ground color	Scald (per cent)	Days marketable	Cause of discard
Air, 32° F.	6/2/39	4.2	4	15	4	Soft
5 per cent CO_2 and 2 per cent O_2, 40° F.	6/2/39	3.5	3.5	40	0	Scald

Until a more complete scald preventative than shredded oiled paper is found, Cortland cannot be recommended for commercial trials in controlled-atmosphere storage.

GOLDEN DELICIOUS

The Golden Delicious apples used in this experiment were from Ulster County in the Hudson Valley. The results with this variety during a one-year trial in one particular atmospheric combination of carbon dioxide and oxygen are shown in table 10. The pressure test was slightly higher in the 32° cold-storage lot, upon removal from storage, because of sponginess. Slightly more shriveling occurred in cold storage than in controlled-atmosphere storage because of a slightly lower relative humidity. There was a slight tendency towards mealiness in the controlled-atmosphere lot upon removal from storage in June. In fact, the only real advantage that seemed to accrue to the controlled-atmosphere lot was the fact that there was somewhat more shriveling in the cold-storage lot. In spite of the fact that well-matured apples and an ample supply of shredded oiled paper were used, a slight amount of scald occurred on a few of the controlled-atmosphere apples upon removal from storage. Coloring matter leached out of the shredded oiled paper because of the high humidity of the controlled atmosphere, and stained the apples with irregular purple spots where the paper touched the apples.

It may be concluded from this limited trial of one year that controlled-atmosphere storage of Golden Delicious did not justify the extra expense. In fact, had the relative humidity of the cold storage been 90–95 per cent, the fruit in this storage would probably have been just as good upon removal from storage.

TABLE 10. EFFECT OF CONTROLLED-ATMOSPHERE STORAGE ON GOLDEN DELICIOUS

Treatment	Date examined	Firmness lost (pounds)	Ground color	Soluble solids (per cent)	Days marketable	Cause of discard
Air, 32° F.	3/7/41	6.3	4	13.6	11	Soft and shriveled
5 per cent CO_2 and 2 per cent O_2, 40° F.	3/7/41	6.4	4	12.4	13	Soft and shriveled

NORTHERN SPY

This variety keeps very well in ordinary cold storage, but the possibility of storing it past its normal season has been examined. The fruit used in this experiment came from Ulster County in the Hudson Valley.

The results for this variety are given in table 11. By March 1 the fruit in ordinary cold storage had lost more firmness than had that held in controlled atmospheres. When removed from controlled-atmosphere storage it kept in a marketable condition for 30 days, whereas that taken from ordinary cold storage kept only 18 days. Bitter pit developed somewhat more in cold storage than in controlled-atmosphere storage, but the final amount was about the same in both instances. In other words, controlled-atmosphere storage merely seemed to delay the appearance of this trouble.

Although controlled-atmosphere storage lengthened the life of this variety, the question would still remain as to whether it would justify the extra expense.

TABLE 11. INFLUENCE OF CONTROLLED-ATMOSPHERE STORAGE ON NORTHERN SPY

Treatment	Date examined	Firmness lost (pounds)	Ground color	Days marketable	Cause of discard
Air, 32–34° F.	3/1/41	8.2	3–4	18	Soft
5 per cent CO_2 and 2 per cent O_2, 40° F.	3/1/41	6.4	3–4	30	Soft

DELICIOUS

Fisher (5) has reported that accumulations of carbon dioxide with this variety in storage seemed to induce mealiness in Iowa-grown Delicious. He had best results with this variety in a very low oxygen atmosphere with no carbon dioxide present. In this study, 5 per cent carbon dioxide and 2 per cent oxygen were used at a temperature of 40°F.

The results from this variety are presented in table 12. Some advantage was obtained by using controlled-atmosphere storage but the effect is not so striking as with some other varieties. The apples removed from controlled-atmosphere storage kept about a week longer at room temperature than did those from cold storage at 32°. No tendency toward mealiness was noted until the June examination, when a slight mealiness was observed. The cold-storage apples were also mealy by this time.

As a result of this one-year study with one atmospheric combination it might be concluded that Delicious did not respond markedly to controlled-atmosphere storage.

TABLE 12. INFLUENCE OF CONTROLLED-ATMOSPHERE STORAGE ON DELICIOUS

Treatment	Date examined	Firmness lost (pounds)	Ground color	Soluble solids (per cent)	Days marketable	Cause of discard
Air, 32° F.	3/7/41	7.1	3	11.6	28	Soft-mealy
5 per cent CO_2 and 2 per cent O_2, 40° F.	3/7/41	6.5	3	12.6	36	Soft-mealy

ROME BEAUTY

Rome Beauty is a variety that usually keeps very well in ordinary cold storage. Controlled-atmosphere storage was tried to see if it could lengthen the storage season.

From table 13 it may be seen that this variety responded rather well to the atmosphere and temperature used (5 per cent carbon dioxide and 2 per cent oxygen at 40°F). The controlled-atmosphere apples finally had to be discarded, while being held at room temperature, because of mealiness and not because of softness. The ordinary-cold-storage apples developed a severe spotting at the lenticels while being held at room temperature; the controlled-atmosphere apples showed no signs of this. Definite conclusions should not be drawn from this one-year experiment. Rome Beauty is fairly susceptible to scald, but during this particular year scald was not a great

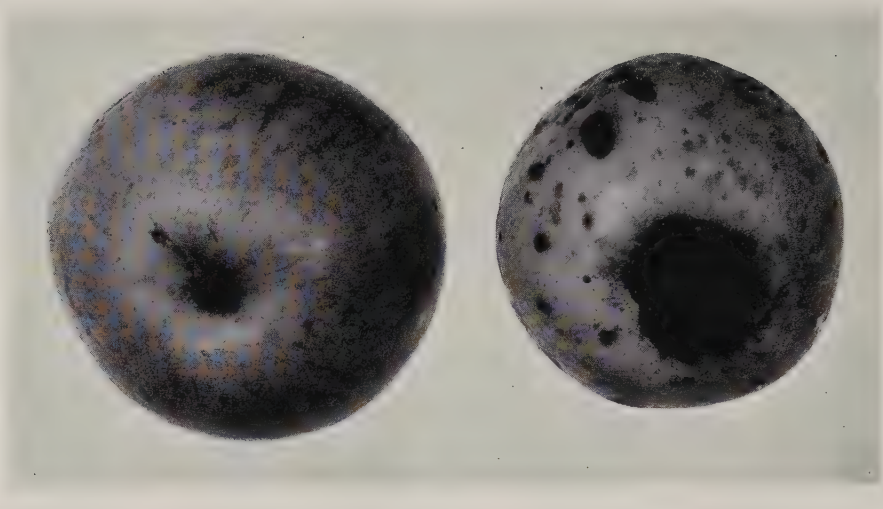

FIGURE 5. ROME BEAUTY REMOVED FROM STORAGE MARCH 7, 1941, AND THEN HELD AT ROOM TEMPERATURE FOR 7 WEEKS
Left, 5 per cent carbon dioxide and 2 per cent oxygen, 40°F.; right, ordinary cold storage, 32°F.

hazard on any variety. In a bad scald year this variety might be unadapted to controlled-atmosphere storage because of this factor alone; further trials should be made to determine how serious the scald hazard year in and year out will be.

TABLE 13. INFLUENCE OF CONTROLLED-ATMOSPHERE STORAGE ON ROME BEAUTY

Treatment	Date examined	Firmness lost (pounds)	Ground color	Soluble solids (per cent)	Days marketable	Cause of discard
Air, 32°	3/7/41	10.2	2–3	13.0	28	Mealiness and spotting
5 per cent CO_2 and 2 per cent O_2, 40° F.	3/7/41	8.1	2	13.0	46	Mealiness

SUMMARY OF VARIETAL RESPONSE

The variety which responded most markedly to controlled-atmosphere treatment was McIntosh. The storage life of McIntosh can be doubled in controlled atmospheres, as compared with ordinary cold storage in air at 32°F. In three of four years, brown core was entirely avoided by use of controlled atmospheres at 40°F. In the fourth year there was not enough brown core in controlled-atmosphere lots to detract from the commercial value of the fruit. At present it would seem that commercial trials should be concerned solely with this variety in New York.

Northwestern Greening, Twenty Ounce, Golden Delicious, Rome Beauty, Delicious, and Northern Spy responded fairly well to the atmosphere tried with these varieties in a one-year test. Scald may cause trouble in the first four, particularly in some years. Since danger of mealiness development has been reported by Fisher (5) with Delicious, further trials probably should be made with this variety also.

Cortland responded well from the standpoint of firmness and crispness but was extremely susceptible to scald one year in a two-season experiment. Rhode Island Greening seemed very susceptible to brown core in an atmosphere with carbon dioxide, and scald was serious one year with this variety. Jonathan was susceptible to a type of internal browning in controlled-atmosphere storage, but Jonathan spot was avoided with this type of storage. Baldwin and Wealthy were seriously affected by brown core in the atmosphere employed in a one-year test.

Further experiments are needed to find a better control of scald so that varieties such as Cortland can be used in controlled-atmosphere storage. Experiments are needed with varieties other than McIntosh to determine the effects of very low carbon-dioxide concentrations or of atmospheres devoid of carbon dioxide and very low in the amount of oxygen.

FRUIT MATURITY

In the 1939–40 storage season, studies were made with McIntosh on the effect of degree of maturity at the time of harvest on keeping quality in controlled-atmosphere storage. Composite samples were made up from the same trees at intervals. Commercial harvest of this variety during this year was from September 18 to September 25. At the first picking, the fruit was from 2¼ to 2½ inches in diameter, and thereafter ranged from 2½ to 2¾ inches. On the last two pickings a few of the fruits were 3 inches in diameter.

These apples were held in an atmosphere of 5 per cent carbon dioxide and 2 per cent oxygen at 40°F.

With this particular lot of fruit, the soluble-solids test and ground color were the best indices of ripening rate on the tree. Ease of separation was a poor test of maturity because after the first picking they all separated rather easily.

It is apparent from table 14 that fruit picked before September 29 was

TABLE 14. EFFECT OF MATURITY AT PICKING TIME ON STORAGE LIFE OF MCINTOSH IN CONTROLLED ATMOSPHERES, 1939–40

Harvest date	Firmness (pounds)	Ground color	Soluble solids (per cent)	Surface color (per cent)	Scald (per cent)	Condition	Quality
			At harvest time				
9/14/39	17.4	1½	12.4	50	...	...	...
9/18/39	16.7	2	12.8	50–60	...	...	...
9/22/39	16.3	2–2½	13.2	70–75	...	...	...
9/29/39	17.7	2–2½	13.7	75	...	...	...
10/6/39	15.7	2½–3	14.2	80	...	...	...
10/13/39	14.3	3–3½	14.8	90	...	...	...
			After storage				
9/14/39	13.0	2–2½	12.2	50	100	Poor	Poor
9/18/39	13.1	2–2½	12.4	50–60	100	Poor	Poor
9/22/39	13.7	2½	13.4	70–75	50	Fair	Fair
9/29/39	12.5	3	13.8	75	0	Good	Good
10/6/39	12.5	3	13.4	80	0	Good	Good
10/13/39	12.7	3	14.4	90	0	Excellent	Fair

subject to scald and was of poor eating quality after storage in controlled atmospheres. In this particular year the best fruit was picked between September 29 and October 6. The last picking had a tendency to be slightly mealy after storage.

During the 1940–41 season, a lot of McIntosh was picked on October 9, after all commercial pickings at Ithaca had been completed for this variety. This fruit had been sprayed with napthalene acetic acid to prevent fruit drop. It was noted that this mature fruit had a slightly higher pressure test than had fruit in many earlier pickings. The fruit was almost 100 per cent fully colored by this time. It was rather mealy at the end of the storage season and there was some tendency for cracking in storage because of overmaturity. It may be concluded from this that McIntosh should not be too mature when picked, although Phillips (13) has suggested that Canadian McIntosh should be picked after the fruit passed its respiratory peak.

The general suggestion is made that McIntosh intended for controlled-atmosphere storage be picked when it reaches the same general degree of maturity as that of McIntosh picked for cold storage. The fruit should be allowed to develop a slightly yellowish ground color on the tree but there is danger of overripeness if it is allowed to hang on the tree too long. If picked when too immature it is subject to scald and will be of low quality.

HANDLING OF FRUIT BEFORE STORAGE

For best results in storing apples in either ordinary cold storage or controlled-atmosphere storage, the apples (particularly if they are McIntosh) must be handled very carefully. Every skin puncture is a potential source of rotting. It is assumed that only high-quality and high-grade fruit will justify the expense and trouble of storing for as long as is permitted by this method. Studies by Lin (11) at Cornell University have shown that, once the fruit has been punctured and inoculated with various rot organisms, controlled atmospheres do not check the growth of these organisms in the fruit any more than does ordinary cold storage. In fact, temperature seems to be more important in this regard than does the nature of the atmosphere. Every precaution must be taken from the time the fruit is picked until it is put into storage to prevent bruising and stem punctures.

The question arises as to whether fruit to be stored in controlled atmospheres should be stored "field-run" or packed. This depends partly upon the marketing practices and the preference of the person storing the apples. There is some advantage in storing the apples field-run in old crates and grading them as they are sold. Old field crates are of seasoned wood and have very little odor to them. Kidd and West (7) recommend the exclusive use of wood which has been seasoned one or two years in the storage crates. When green wood is used in storage containers the odor in a closed chamber may become quite strong by the end of the season. The apples tend to absorb some of these odors and may taste of "box odor" at the time they are removed from storage. Several days of airing after the storage room is unsealed should remove this odor from the fruit. If a source of ozone is available, several days' exposure to 1-2 parts per million of ozone in the atmosphere will destroy these odors. If the fruit is to be wrapped in oiled paper there is of course some advantage in putting it into the market container at the time of harvest to save one handling operation. The

same is true to a lesser extent with the use of shredded oiled paper, because less handling is required. Some storage operators have practiced a slight grading operation at the time the fruit was mixed with the shredded oiled paper before storing, removing the obvious culls but making no attempt at sizing or close grading.

Somewhat better air distribution is obtained in a loosely packed unlidded container, such as a field crate, than in the market container.

Not only the fruit but the oiled paper tends to absorb some of the woody or musty odor that may develop in the gastight room. One advantage of using shredded oiled paper on fruit packed after storage is that the paper is removed before the fruit goes on the market place. Not only is a source of odor removed with the paper, but some buyers object to quantities of paper in the market package.

The interval between the time of picking and the time the room is sealed should be as short as possible. Where McIntosh apples were being put into commercial rooms, filling and sealing the rooms during the normal picking season for that variety proved satisfactory. That is, the room should be filled and sealed within at least ten days or two weeks after the start of the McIntosh harvest. During the filling period the temperature of the room can be 32–34°F. As in cold-storage practice, the field heat should be removed as soon as is feasible. Then when the room is sealed, the temperature is raised to 40°F. Air circulation during the loading period, of course, facilitates fast cooling.

It is particularly important during the loading period that the relative humidity be kept as high as possible. Further discussion of this point is given in another section (page 40).

FILLING THE STORAGE ROOM

It is most important that the storage room be full; if only partially filled, carbon dioxide builds up rather slowly, and, even more important, the oxygen is reduced very slowly. In a gastight room which is filled with fruit, the oxygen should be lowered to 2 per cent within a month or slightly longer. In a gastight room which is only half full it may require two months or longer to reduce the oxygen to the desired point. In a 13,000-bushel room which was three-quarters filled with fruit and which had a normal leakage rate of 6 per cent each day, the oxygen was not lowered to 3 per cent until after 3½ months. In other words, the reservoir of oxygen was so great in this room and the volume of fruit was so small that with this leakage, oxygen from the outside leaked into the room almost as fast as respiration used it up.

Provisions for air circulation in stacking should be at least as liberal if not more so than in cold-storage practice. The crates should be stacked one or two inches off the floor, and if the fruit is in closed market containers, stripping of the tiers is feasible. Space at the walls and ceiling should be ample to supply good circulation.

STORING DIFFERENT VARIETIES TOGETHER

Kidd and West (*7*) make a point of having separate chambers for different varieties. One reason for this is that different varieties may have different atmospheric requirements in storage. A second reason offered by Kidd

and West (10) is that one variety may tend to ripen another in a gastight room. Ethylene evolved from a rapidly ripening sort may actually ripen a later variety faster in a gastight room than in cold storage. They have observed "ethylene injury" from naturally evolved ethylene coming from one variety and affecting another variety.

In preliminary trials at Cornell it has been shown that it is preferable to store varieties separately in controlled atmospheres. For example, it was found that Wealthy scalded when stored with McIntosh and did not scald when stored alone. Dutchess seemed to cause scald in Northern Spy when stored with it. Also Rhode Island Greening scalded when stored with McIntosh in a gastight chamber, whereas Rhode Island Greening alone did not scald in the 1940–41 season.

Since McIntosh is the principal New York variety adapted to this procedure, the problem of storing varieties together is not so serious as it might be. It should be emphasized, however, that in the light of present information no other varieties should be stored with the McIntosh.

SCALD CONTROL

Scald is apparently caused by accumulations of certain volatile substances emanated by the fruit around the skin of the apples. The more restricted the ventilation, the more likely is scald to occur. In controlled-atmosphere storage, restricted ventilation is the predominant feature, and scald may cause trouble unless precautions are taken for its control. Even McIntosh which usually does not scald in storage may do so in controlled-atmosphere storage. Cortland scalds very badly unless stringent measures are taken, and in some years it may scald in controlled-atmosphere storage in spite of all precautions.

The standard recommendation for scald control has been one-half pound of freshly prepared shredded oiled paper (with not less than 15 per cent by weight of tasteless, odorless mineral oil) well mixed with the apples in each bushel. Control of scald of McIntosh has been obtained in an atmosphere of 5 per cent carbon dioxide and 2 per cent oxygen, with only ¼ to ⅓ pound of shredded oiled paper well mixed with the fruit. When higher concentrations of carbon dioxide are used, more paper is likely to be needed since scald susceptibility is increased (18). Use of a washer in maintaining this atmosphere also seems to reduce scald somewhat, since the alkali dissolves some of the volatiles which cause scald. Where oiled-paper wraps are used, excellent control is obtained on the less susceptible varieties. These usually add more to the cost because of the extra labor expense for wrapping the fruit. Two commercial-storage operators in 1940 wrapped at least part of the fruit stored in controlled atmospheres.

The use of shredded oiled paper is objectionable from a number of standpoints. So much is required in each box of fruit that buyers object to it because of the litter it makes when the fruit is unpacked. If when the fruit is brought out of storage there is some condensation on its surface, the paper sticks to each fruit and must be pulled off. The paper has a considerable drying effect on the atmosphere. That is, it lowers the relative humidity of the room. Of course, this can be compensated for by adding sufficient water vapor to the air during the loading period to satisfy the "water requirement" of the paper. It absorbs odors. During storage in con-

trolled atmospheres the woody odor emanating from the containers may become rather strong. This can be eliminated by methods described under another section (page 18), but the paper seems to retain the odors even longer than does the fruit. One advantage in storing apples field-run or nearly so, mixed with shredded oiled paper, is that the paper is removed during the grading process and apples "air out" much more quickly than they do when wrapped in oiled paper that is left on the fruit. Oiled wraps and shredded oiled paper add to the cost of the package considerably. Finally, oiled paper does not control scald on the highly susceptible varieties in controlled-atmosphere storage.

In spite of the objections to oiled paper, it is still the only satisfactory means of preventing scald on the less susceptible varieties in controlled-atmosphere storage. It is recommended that, if the fruit is not wrapped, from ¼ to ⅓ pound of shredded oiled paper be well mixed with each bushel of McIntosh.

CARBON-DIOXIDE TREATMENTS BEFORE STORAGE IN CONTROLLED ATMOSPHERES

Brooks (3) has pointed out the possibility of treating apples with rather high concentrations of carbon dioxide for relatively short periods prior to cold storage. This experiment was designed to test the effectiveness of this procedure with McIntosh both in cold storage at 32°F. and in controlled-atmosphere storage.

Uniformly mature McIntosh were treated for one, two, or three days with 40 per cent carbon dioxide in gastight chambers at 40°F., and then one lot of each treatment was moved into cold storage at 32° and into an atmosphere of 5 per cent carbon dioxide and 2 per cent oxygen at 40°. Another lot was treated with 55 per cent carbon dioxide for three days and moved into the two storage treatments mentioned above. During the course of each 24-hour period of the carbon-dioxide treatments, the concentration of this gas dropped about 10 per cent from the initial values of 40 and 55 per cent. The concentrations were brought back up to the desired value each day during the carbon-dioxide treatments. Treatments began on October 2, 1940, and the fruit was examined after storage on March 1, 1941.

The results of these carbon-dioxide treatments are shown in table 15. The air check at 32° lost 5.2 pounds in storage and the fruit in the carbon-dioxide treatments followed by cold storage lost approximately the same amount, although the fruit in the 55 per cent carbon-dioxide treatment lost slightly more. The carbon-dioxide treatments seemed to have had no effect on the amount of brown core in later storage at 32° in air. The carbon-dioxide treatments apparently added about two days to the length of time the fruit was marketable at room temperature and high humidity after storage. In controlled-atmosphere storage the apples without any prior treatment lost only 3.9 pounds, whereas the carbon-dioxide-treated apples lost somewhat more than this. There was no consistent effect of the carbon-dioxide treatments on the amount of brown core, although there was distinctly less brown core in all the controlled-atmosphere lots than in the cold-storage lots.

It may be concluded that carbon-dioxide treatments prior to cold storage

TABLE 15. EFFECT OF CARBON-DIOXIDE TREATMENTS PRIOR TO STORAGE ON McINTOSH KEEPING QUALITY

Treatment	Firmness lost (pounds)	Soluble solids (per cent)	Brown core		Days marketable	Cause of discard
			After storage* (per cent)	After 12 days (per cent)		
Air, 32° F.	5.2	12.4	53.0	100.0	11	Soft, and brown core
40 per cent CO_2 1 day, then 32° F. air storage	5.1	12.3	50.0	100	14	Soft, and brown core
40 per cent CO_2 2 days, then 32° F. air storage	5.0	12.2	45.0	95.0	13	Soft, and brown core
40 per cent CO_2 3 days, then 32° F. air storage	5.1	12.4	60.0	95.0	13	Soft, and brown core
55 per cent CO_2 3 days, then 32° F. air storage	6.0	12.7	45.0	100.0	13	Soft, and brown core
Controlled atmosphere at 40° F. (check)	3.9	12.2	14.0	14.0	30	Soft
40 per cent CO_2 1 day, then controlled atmospheres at 40° F.	4.6	12.6	10.0	10.0	30	Soft
40 per cent CO_2 2 days, then controlled atmospheres at 40° F.	5.3	12.8	20.0	20.0	30	Soft
40 per cent CO_2 3 days, then controlled atmospheres at 40° F.	4.9	12.8	0	10.0	30	Soft
55 per cent CO_2 3 days, then controlled atmospheres at 40° F.	5.6	12.3	10.0	10.0	30	Soft

*March 1, 1941.

had a slight but insignificant effect in lengthening the storage life of McIntosh in this experiment. Carbon-dioxide treatments prior to controlled-atmosphere storage at 40° had no beneficial effect.

CONSTRUCTION OF THE CONTROLLED-ATMOSPHERE CHAMBER

SIZE

Kidd and West (7) do not recommend chambers larger than 2000 bushels in size. The first commercial trial in New York State in 1939 was with a room of 2500-bushel capacity, and extremely good results were obtained. In 1940, when five other commercial rooms were built, they ranged in size from 2000 to 13,500 bushels in size.

It would seem that as long as ample provision is made for air circulation in the room, and if the room can be filled each season, size of the room is not an important factor of itself. Size of the room should be determined more by the ability of a grower or group of growers to fill the room and by the quantity of fruit which they wish to hold for the late-season market.

METHODS OF MAKING THE ROOM GASTIGHT

1. The traditional English method (7) of making chambers gastight has been to use 28-gauge sheet metal laid down on wooden grounds inside the insulation. The sheets are overlapped at the joints and nailed down on a layer of vaseline at the joints.

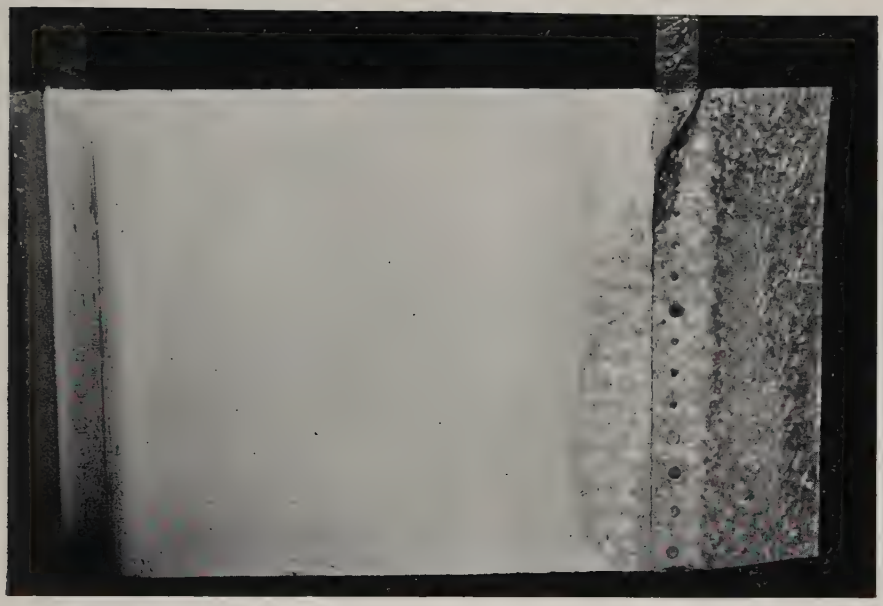

FIGURE 6. METHOD OF PUTTING UP SHEET-METAL LINING FOR GASTIGHTNESS

FIGURE 7. INTERIOR OF EXPERIMENTAL CONTROLLED-ATMOSPHERE CHAMBER
Gastight seal is supplied by use of sheet metal. Cooling unit in foreground

Two rooms in New York have been constructed this way, with some modifications. Twenty-eight-gauge sheet galvanized iron is sufficiently heavy. Copper or other alloy metal is more resistant to corrosive action than is ordinary sheet metal. It is advisable, however, to paint both sides of the sheet metal before installation to check corrosive action of the dissolved carbon dioxide condensed on the metal or the rusting action of water itself. Width of the sheets is determined by the distance between studdings on which the sheets are nailed. The sheets should be overlapped about one and one-half inches and nailed down on a layer of soft, gun-grade caulking compound. Gun grade is probably the best consistency since it can be applied with a gun applicator, and this speeds up the application rate. Large-headed galvanized roofing nails driven through the overlapped metal every two inches will draw the sheets down tightly on the putty. Any excess of putty squeezed out during the nailing operation can then be smoothed down with a putty knife and removed. Putty should be placed around the nailheads carefully to insure a seal at this point. After installation and some drying of the putty at the surface, it is advisable to give the metal a final coat of good metal paint, such as machinery-finish grade.

Before any painting of the sheet metal, particularly if it is glazed, it should be washed with a dilute vinegar solution and allowed to dry. This permits adherence of the paint to the metal.

If the floor is to be made gastight by using sheet metal, the metal must be laid on a solid wooden subfloor to prevent sagging with the weight of

FIGURE 8. INTERIOR OF 2200-BUSHEL, CONTROLLED-ATMOSPHERE ROOM MADE GASTIGHT BY USE OF SHEET METAL
Cold-air diffuser in right foreground

the fruit. The metal floor should be protected by the use of boards or heavy roofing paper (preferably not tar paper) on the aisles.

2. In many already existing storage rooms, cork insulation has been plastered over. This plaster, with proper care, can be made at least 95 per cent gastight. Three rooms have been made gastight by this procedure in New York. Phillips (12) describes a similar procedure in Canada. All major plaster cracks should be replastered. All minor cracks should be well filled with putty similar to that described under "1".

FIGURE 9. INTERIOR OF 7000-BUSHEL, CONTROLLED-ATMOSPHERE ROOM MADE GASTIGHT BY USE OF PAINT OVER PLASTER

Ceiling cooling coils with drip pans can be seen, and also one of two large fans used for air circulation in this room

All openings in the walls and ceiling must be sealed with putty or some other sealing compound. After the room has been filled, light bulbs may be removed and sockets sealed over, or glass fittings may be put around the bulbs and caulked in carefully.

In the preparation of the plaster walls for painting, any foreign material such as whitewash must be removed with a wire brush. The plaster walls and concrete floors should then be brushed or sprayed with a solution of zinc sulfate (3 pounds of crystals in a gallon of water). After this solution is dry, the crystals should be brushed off with a wire brush. New masonry or plaster must be allowed to age from 60 to 90 days before painting it.

For a first coat, a primer sealer should be applied undiluted. This material is rather gummy and resinous and should be well brushed into the pores. Brushing of this material is better than spraying. This coat should be al-

FIGURE 10. INTERIOR OF CONTROLLED-ATMOSPHERE ROOM MADE GASTIGHT BY THE USE OF PAINT ON THE PLASTERED WALLS

lowed to dry for from 18 to 24 hours at a temperature of 65°F. or higher. Heaters may be used in the room to facilitate drying. If, after this application, "suction areas" appear, a second coat of this material should be applied to these areas. For a second coat, a good quality "undercoater" should be applied at the consistency recommended by the manufacturer. After this is dried, a coat of white gloss paint should be applied at the consistency recommended by the manufacturer.

Concrete floors should be prepared in the same way as the plaster walls. The first coat of paint should be machinery finish, diluted according to the manufacturer's directions. The second coat should not be diluted.

After the paint is thoroughly dried, the room should be thoroughly aired to free it of any paint odors before the fruit is brought in.

The painted floors should be protected in a manner similar to that described for the sheet metal. The paint will require retouching from time to time, and new cracks should be filled each season.

3. For new buildings, or even old buildings, aluminum foil may be used as the gas seal. In new buildings several layers can be installed, and it will serve as both a gas seal and insulation. Studies (21) have shown that this material when properly installed has merit from the insulation standpoint. Two rooms have been made gastight by this means in New York. The aluminum foil used was on heavy kraft paper with a coating of foil on each side of the paper.

FIGURE 11. METHOD OF PUTTING UP ALUMINUM-FOIL INSULATION AND GAS SEAL
The joints are overlapped and caulking compound is used

The foil is nailed down in putty on wooden grounds in much the same manner described for sheet-metal installations (page 24). One layer should be sufficient for a gas seal if properly installed, but a number of layers are used for insulation purposes. All layers are spaced ½ to 1 inch apart. If aluminum foil has been used as a gas seal in the floor, tongue and groove flooring is laid over the aluminum foil.

Precautions must be taken to see that the foil has no pinholes or other defects before installation. After installation it should be covered with some protective sheeting.

4. One trial has been made with a patented steel structure of 300-bushel capacity. The distinctive feature of this structure is that the metal gastight seal is on the outside. Steel "tensioners" fasten over curved edges of the constituent sheets of "galvanealed" metal, on caulking compound to insure gastightness at the joints (figure 13). This room proved to be sufficiently gastight. This type of chamber would probably be more adaptable, however, to small storage chambers for carbon-dioxide treatments of small fruits than to large apple-storage rooms.

FIGURE 12. WALL AND CEILING OF A 13,500-BUSHEL, CONTROLLED-ATMOSPHERE ROOM, MADE GASTIGHT BY PAINT ON WALLS AND ALUMINUM FOIL ON CEILING

THE GASTIGHT DOOR

While it may be possible to so construct or alter the insulated door and to seal it shut in such a way as to have it gastight, it is probably preferable to have a separate gastight door.

The door may be made of sheet metal tacked on a wooden frame, with the nailheads covered with putty. It can be made of two layers of aluminum foil sealed on kraft paper tacked on a light frame and surfaced over with plywood. This door can be installed inside the casement of the insulated door and can be fitted to draw down on a 2 x 2-inch shoulder on sponge-rubber gaskets. Vaseline or a light grade of cup grease can be used in fastening down the door to make the seal tight. Wedge bolts can be used to draw down the door on the frame. A glass sliding window of 10 x 12-inch dimensions can be installed in the door at the eye level for examination of the fruit at intervals. A window large enough for a man to crawl through may be preferable. This window should also be sealed in vaseline or cup grease (figure 14).

LEAKAGE TESTS

If there is any question about the gastightness of a room prior to its use for controlled-atmosphere storage, it should be tested. Such tests have been made by sealing the room and maintaining a temperature of 40°F., with the air circulation comparable to what it would be when the room is in operation. Carbon dioxide from cylinders can be used at fairly small expense. A small opening should be left in the room during the entrance of the gas to release any accumulation of pressures. It is preferable to use enough carbon dioxide to build up a concentration of at least five per cent.

FIGURE 13. TWO 300-BUSHEL EXPERIMENTAL CHAMBERS USED IN THIS STUDY
Left, insulated and gastight door with glass inspection port and trap for excess water from the cooling unit
Right, door with metal gastight seal on the outside of the insulation

A 50-pound cylinder of carbon dioxide will fill about 6750 cubic feet of storage space with 5 per cent of carbon dioxide.

In figure 15 are illustrated results obtained in measuring the leakage in a gastight steel structure of 300-bushel capacity. This study was made to determine how much carbon dioxide should be used in studying leakage. An initial concentration of 14 per cent was used. The blowers were operated continuously in the chamber. The leakage was faster during the first two days than at any other time. This initial leakage rate was high partly because of a higher concentration of gas, but it is thought that the kapok insulation inside the gastight seal had to be first saturated with gas. The leakage rate during this period was about 11 per cent per day. During the next 12 days the leakage rate was only about two per cent per day. From the fourteenth to the twentieth day the washer was run to determine the effect of the washer blower on leakage. The washer was empty at this time, but had not been cleansed of any possible residues of caustic soda. The leakage rate during this period was about 7 per cent per day. During the last eleven days of the test the washer was turned off and the leakage was about 3 per cent per day.

As a result of this test, the following conclusions might be drawn. Five per cent carbon dioxide, as an initial concentration, would seem to be suffi-

FIGURE 14. ENTRANCE TO A CONTROLLED-ATMOSPHERE ROOM, SHOWING METAL, GASTIGHT DOOR WITH LARGE WINDOW, AND INSULATED DOOR ON OUTSIDE

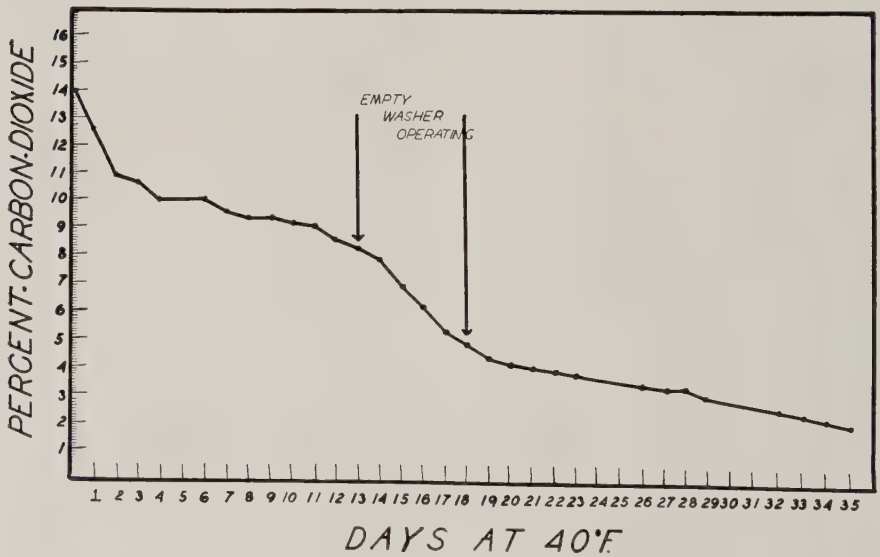

FIGURE 15. RATE OF LEAKAGE OF CARBON DIOXIDE FROM GASTIGHT METAL-SHELL STRUCTURE

cient to measure leakage. The test should continue for several days. About four to six hours should be allowed for the gas to be well mixed in the room before the initial reading is taken for the actual leakage test.

The question arises as to how much leakage a room can tolerate and still be sufficiently gastight for this procedure of storage. It would seem that the rooms should be *at least* 90 per cent efficient. That is, during a 24-hour testing period, a loss of 10 per cent of the total carbon dioxide present might be allowable. Kidd and West (*7*) maintain that no rooms are perfect, and that even the best have a leakage of 5 per cent. It would seem safe to say that the rooms should be at least 90-per-cent gastight but preferably 95 per cent. If a room is only partially filled, it is even more important that the gastightness be 95 per cent.

Care in workmanship, of course, determines in large part how successful a given method of attaining gastightness will be. In table 16 are indicated

TABLE 16. LEAKAGE TESTS WITH VARIOUS CONTROLLED-ATMOSPHERE CHAMBERS

Test	Type of chamber	Size of chamber	Leakage of CO_2* (per cent)
1	Sheet-metal lining	300 bushels	3.3
2	Sheet-metal lining	2,000 bushels	4.4
3	Steel-shell structure	300 bushels	3.0
4	Paint over plaster	2,000 bushels	7.6
5	Paint over plaster	13,500 bushels	7.4
6	Aluminum foil	20 bushels	2.5
7	Aluminum foil	2,000 bushels	5.0
8	Aluminum foil	9,000 bushels	10.5

*Tests made with approximately 5 per cent carbon dioxide over 24-hour periods at temperature of 40° F.

some variations in the same type of construction, but there were variations in size of the rooms and also in the care with which the gastight seals were made.

REFRIGERATION EQUIPMENT

No special refrigeration equipment is needed for controlled-atmosphere storage. Refrigeration equipment sufficient to maintain the desired temperatures is essential. It must also be of sufficient capacity to bring down fruit temperature to 40°F. after loading, within a reasonable period of time. The blower type of evaporator used in many farm cold storages seems ideally suited to this procedure because it supplies air circulation. If a room which is being remodeled for controlled-atmosphere storage has pipe coils for cooling, provision should be made for air circulation. In one storage room of 10,000-bushel capacity, two fans with a capacity of 5000 cubic feet per minute, appropriately spaced, have proved sufficient. Of course, all temperature controls must be on the outside of the room; that is, manual or automatic controls for the expansion valve.

Experience has shown that if blower fans are in good working order they will run six months without any attention. They do not seem to produce any odors. Kidd and West (*7*) provided a spindle and oil gland for the fan so that the fan motor could be on the outside of the room. Experience in New York has not indicated any necessity for this.

The size of refrigeration equipment is determined not so much by what the holding temperature will be, but rather by how quickly field heat is to

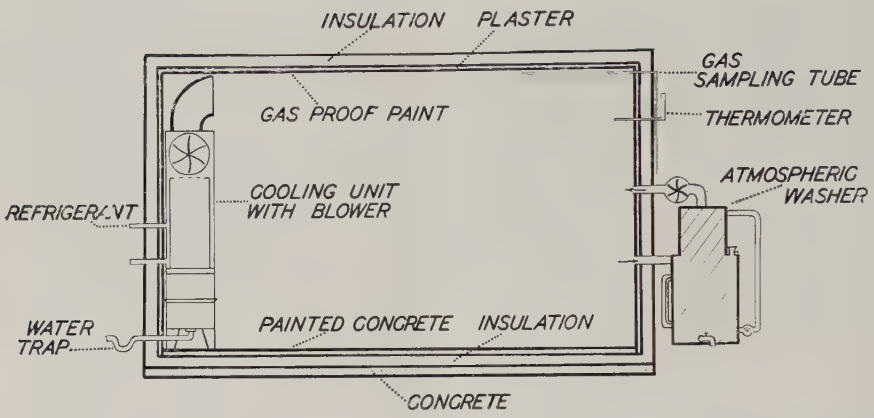

FIGURE 16. LONGITUDINAL SECTION OF A CONTROLLED-ATMOSPHERE CHAMBER, SHOWING ARRANGEMENT OF EQUIPMENT

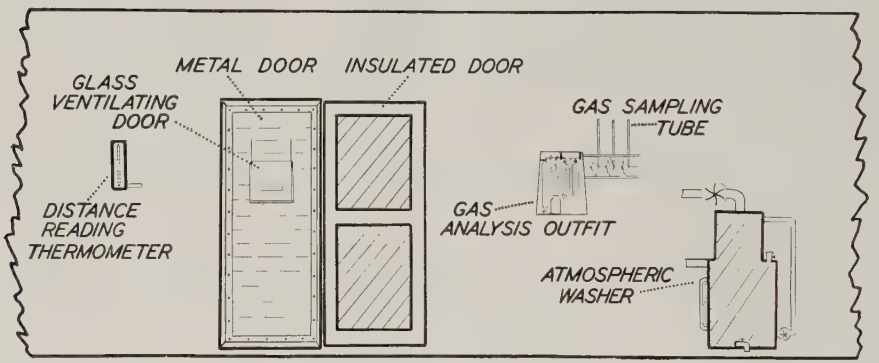

FIGURE 17. DOORS AND NECESSARY EQUIPMENT OF A CONTROLLED-ATMOSPHERE CHAMBER

be removed. Even though the holding temperature is to be 40°F., the refrigeration equipment must be of sufficient capacity to bring down fruit temperature to the desired point within a week at most. The room should be held at 32–36°F. during the loading period. Then, too, a holding temperature of 32–36° may be desired after the room has been opened and the fruit is being marketed. In other words, it would seem advisable to have almost as much, if not fully as much, refrigeration capacity as for ordinary cold storage at 32°. Information on refrigeration equipment and calculation of refrigeration capacity is given in *Farm Refrigerated Storages,* by Earl L. Arnold (Cornell University Agricultural Experiment Station, Bulletin 724, 1939).

Since the storage chamber is presumably not to be entered for five or six months, every precaution must be taken inside the room against leaks of the refrigerant. All joints must be properly tightened in the pipe lines. It is advisable to test the storage-room atmosphere frequently for ammonia leaks. This can be done by smelling it through openings in the washer.

The question arises as to what should be done with condensation water coming from the cooling surfaces of the blower or the pipes. The English follow the practice of leading this excess water to the outside through a water trap which will stand a pressure of one inch of water. Some of the commercial operators in New York have allowed this condensation water to drain out on the floor of the storage. This helps keep the humidity high. Some have piped off excesses of water through a water trap, which prevents leakage of the atmosphere out of the room.

AIR CIRCULATION

Considerable air circulation is required in the chamber to prevent stratification of both temperatures and atmospheres. Circulation is needed to keep more or less identical concentrations of oxygen and carbon dioxide throughout the entire room. As has been indicated previously, the fans in the blower coolers seem adequate for this purpose. If pipe coils are in use, large fans should be placed in the room in appropriate places, as has been indicated.

Kidd and West (*7*) have recommended continuous air circulation, although some English operators turn the fans off during the night. No information has been obtained on this point at Cornell. All New York operators to date have practiced continuous air circulation. It is possible that running of the fan during only half of each 24-hour period might be sufficient.

Proper stacking of the fruit (page 19) also facilitates air circulation.

INSULATION REQUIREMENTS

In deciding whether less insulation can be used for this type of storage, since a temperature of 40°F. is to be maintained, it must be remembered that insulation is supplied in this climate to protect the fruit against outside subzero temperatures, as well as to prevent heat infiltration in the fall and spring. In addition, the operator may want to operate the storage at 32–36° during the marketing period. It would seem then that just as much insulation should be employed as for cold storage at 32°F.

THE ATMOSPHERIC WASHER

To prevent accumulations of carbon dioxide over 5 per cent in the sealed storage chamber, it is necessary to remove part of this gas without introducing too much outside air.

Accordingly, a unit using sodium hydroxide (caustic soda) as the absorbing agent has been developed. A dilute solution of flake caustic soda is circulated by a small centrifugal pump into the top of a tower, from which the solution flows down through a series of perforated baffle plates to the reservoir below (figure 18). The atmosphere from the fruit-storage chamber is circulated by a small, airtight blower. It is drawn from the storage room into the washing unit and up through the baffle system, after which it is returned to the fruit-storage room. The size of the solution reservoir on the washer may vary from 20 to 100 gallons, depending on the quantity of fruit in the storage and on the length of time the unit is to be operated before renewal of the solution. In a storage chamber of 2000 bushels of McIntosh apples, a unit with an air flow of 154 cubic feet per minute and a

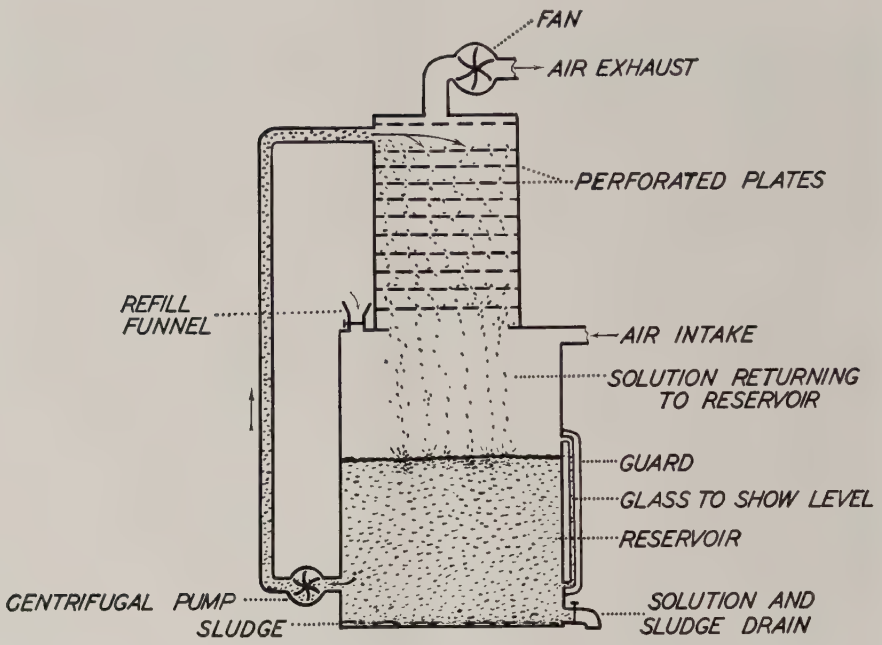

FIGURE 18. LONGITUDINAL SECTION OF ATMOSPHERIC WASHER USED FOR REMOVAL OF EXCESSES OF CARBON DIOXIDE

solution-pumping capacity of 6 gallons per minute, used almost 30 gallons of solution daily, with one-third pound of flake caustic soda per gallon. It provided ample removal of excess accumulation of carbon dioxide from the atmosphere in the closed chamber.

Twelve baffle plates, 24 inches in diameter, in the absorption tower, are spaced 3 inches apart and perforated with five-eighths-inch holes. These holes are spaced 2 inches apart on each plate. The large and numerous holes permit a ready flow or trickle of solution downward and a large volume of air movement upward, thus bringing the storage air into contact with the alkali solution.

The atmosphere is introduced into the unit through a 4-inch pipe just below the baffle plates and above the solution in the reservoir. It is drawn through the unit by the airtight blower, and exhausted into the storage room directly from the blower through a 4-inch pipe.

A water glass on the side of the reservoir is graduated to indicate the gallons of solution. A filling plug and drain valve are 2 inches in diameter, and facilitate change of solutions. One-inch rubber hose and fittings were used as connections for the solution pump in order to facilitate an occasional cleaning of hose and pump.

Fourteen-gauge black iron proved satisfactory for the unit, since the alkali has but slow corrosive action on this material. Both arc-welding and brazing are good methods of construction. For a 5000-bushel storage, one unit, with a reservoir capacity of 60 gallons of solution and a tower containing 15 thirty-inch baffle plates, is adequate. For storages of more than

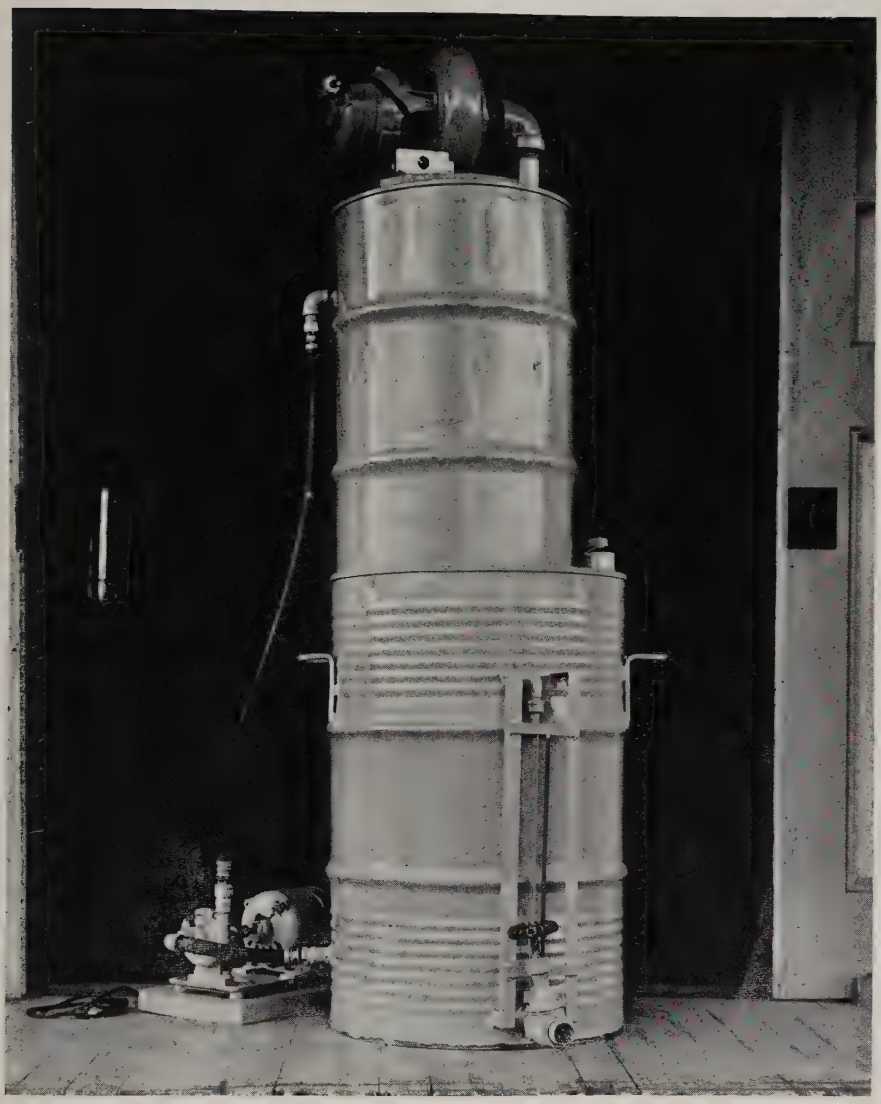

FIGURE 19. ATMOSPHERIC WASHER CONSTRUCTED FROM DISCARDED OIL DRUMS
This size is adequate for a room of about 2000-bushel capacity

5000-bushel capacity, two such units are recommended for each 10,000 bushels of stored fruit. The air blower on each of these units should have a capacity of approximately 200 cubic feet of air movement per minute. The solution pumps should circulate about 10 gallons of solution over the baffle plates per minute. The volume, strength, and frequency of change of the solution are highly important factors in obtaining the most efficient and successful operation of these atmospheric scrubbers, but experience with

FIGURE 20. TWO ATMOSPHERIC WASHERS OF SUFFICIENT SIZE TO MAINTAIN THE CARBON DIOXIDE AT THE PROPER LEVEL FOR 7000 BUSHELS, WHEN BOTH ARE OPERATED
Orsat apparatus may be seen at upper right

several large storage chambers has shown that these units are satisfactory. To what extent these washers remove other harmful gases and products of respiration from the storage air has not been determined, but washing may remove some of the scald-inducing gases.

MEASUREMENT OF TEMPERATURE, HUMIDITY, CARBON DIOXIDE, AND OXYGEN

The temperature inside the controlled atmosphere should be checked regularly. A thermometer can be hung inside the glass window in the door, but a distance-reading thermometer is preferable. Thermometers whose stems extend through the wall and into the storage atmosphere are available on the market. Some of these are of the dial-indicator type. It is also possible to use thermocouples and have an electrical indication of temperatures.

Thermocouple wires can be placed anywhere in a room or in a number of rooms, and all read from a central indicator with a multiple switch. The expense of these is their only limitation. They should be checked each season with accurate thermometers. If air circulation is good, a single temperature reading seems to be adequate for a fairly large room.

The relative humidity should be watched not only throughout the entire storage season but particularly during the loading period. The most satisfactory means of measuring relative humidity before the room is sealed is to use a sling psychrometer. Further information is given in *The Storage of Apples,* by R. M. Smock (Cornell Extension Bulletin 440, 1940). From the wet- and dry-bulb readings the relative humidity can be determined from appropriate tables or quick-reading charts or "slide rules". An electrically aspirated psychrometer is more accurate but also more expensive. Direct readings of the approximate relative humidity can be made during the storage season with hair hygrometers (figure 3, Extension Bulletin 440). These are not accurate and should be checked frequently with a psychrometer, but a sling psychrometer cannot be used once the room has been closed. The direct-reading hygrometer is placed inside the glass window of the door so that it can be easily read.

Carbon dioxide and oxygen must be measured daily. These gases may be measured by use of an Orsat apparatus (figure 21). Carbon dioxide is first absorbed from a 100 c.c. sample of the atmosphere in a 25–30-per-cent solution of potassium hydroxide. The carbon-dioxide-free gas is then measured for oxygen in an absorption tube containing pyrogallic acid in potassium-hydroxide solution (100 grams pyrogallic acid dissolved in 1000 c.c. of saturated potassium-hydroxide solution). This latter material is more efficient as an absorption agent if it is allowed to age for a short time in the dark before being used. At least one proprietary mixture for the absorption of oxygen is on the market. This mixture comes ready for use and is more efficient in oxygen removal than is pyrogallic acid. It is slightly more expensive per unit volume, however.

There are automatic carbon-dioxide indicators on the market. Those which were tested were not accurate, and had to be checked rather frequently with an Orsat apparatus. Indicators for oxygen are expensive, and probably also require checking with an Orsat or similar apparatus.

Copper tubing of ⅛- to ¼-inch bore may be used to pipe the samples of atmosphere from the room to the Orsat apparatus. In a room of 5000-bushel capacity with good air circulation, only one sampling tube is necessary. It should not be placed near a ventilating port or near the outlet pipe of the atmospheric washer.

MAINTENANCE OF THE PROPER ATMOSPHERE

After the room has been filled with fruit and the door sealed, the carbon-dioxide percentage of the air in the room soon begins to increase. In a room filled with fruit, and with a low leakage rate, the carbon dioxide may increase at the rate of 1.5 to 2.0 per cent per day. The oxygen begins to decline at the rate of one per cent a day, or slightly less, in such a room. The oxygen decline is slower than the carbon dioxide increase because the differential between inside and outside concentrations is greater with this gas. If the room is only partially filled, the carbon dioxide builds up at the

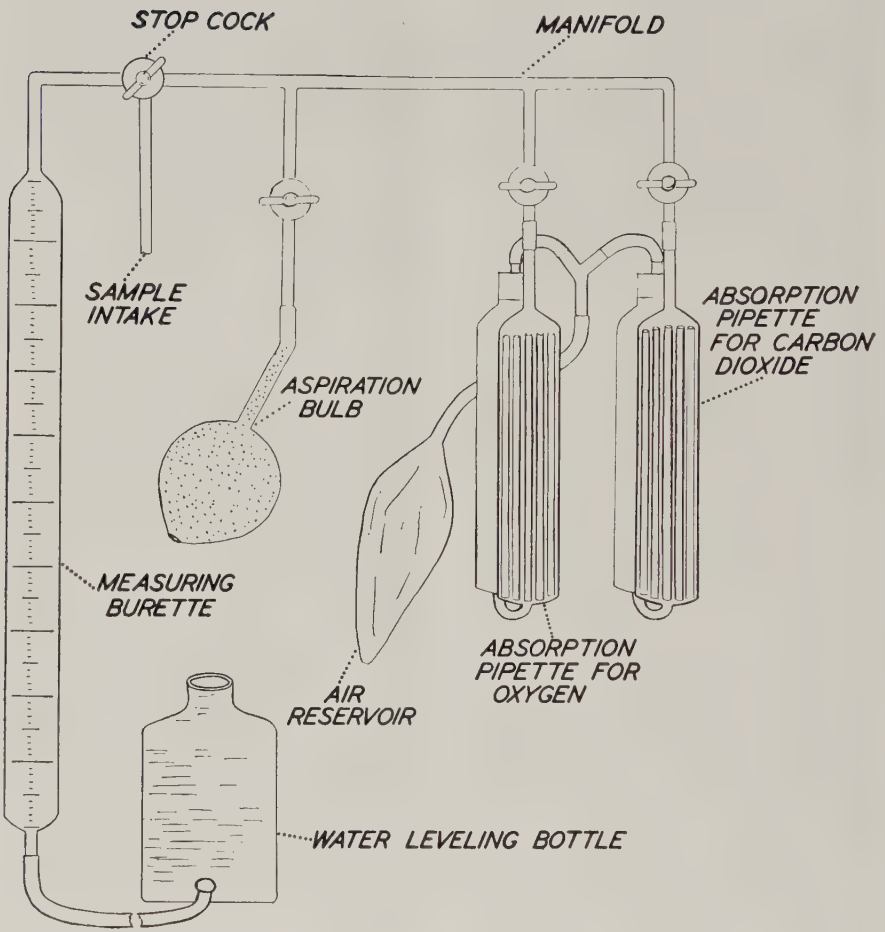

FIGURE 21. SKETCH OF ORSAT APPARATUS FOR MEASURING CARBON DIOXIDE AND OXYGEN IN ATMOSPHERE

rate of 1 per cent or less per day, and the oxygen at the rate of ¼ per cent or less. Disappointing results are likely to be had with a partially filled room because it may take two or three months to get the oxygen down to 2 per cent. Where leakage rates may be slightly high or the room only one-half filled or less, the oxygen may never go down as low as 2 per cent.

It is a common practice to start running the atmospheric washer when the carbon dioxide reaches the 5–6-per-cent level. Some operators start running their washers when the carbon-dioxide level reaches 3 or 4 per cent, with the idea of not letting the percentage of this constituent reach 5 per cent until the oxygen has been reduced below 10 per cent or less. In any event, the washer should be started by the time the carbon-dioxide level has reached 6 per cent, and should be run continuously until the level is brought back down to 5 per cent.

Flake caustic soda is dissolved in a five-gallon pail with water before placing it in the reservoir of the unit. The desired amount of water to make the proper dilution is added. Most successful operation will be obtained with about one-half pound of caustic soda per gallon of water, but this may be varied up to one pound per gallon if more rapid absorption of carbon dioxide is desired. However, at the higher concentration more trouble is encountered with clogging of the unit than when more dilute solutions are used.

Usually when the unit with one-half pound per gallon of solution is operated in a large storage in which the atmosphere contains 5 to 7 per cent carbon dioxide, the ability of the solution to absorb and remove sufficient quantities of carbon dioxide is exhausted after 12 to 24 hours. The solution and sludge should be drained immediately from the unit, and a charge of 25 to 50 gallons of clear water put in the unit, and circulated for a few minutes to rinse out sludge and dissolve carbonates formed on the baffle plates. This solution is then drained off and a new charge of solution put in for further operation as desired.

Analysis and careful tests of samples from the atmosphere going into the washer and from the atmosphere leaving the washer will show the operator when to change solutions and just how great a percentage of the carbon dioxide is being removed from the air as it passes through the washer. The washers need not be operated when the carbon-dioxide content is below 5 per cent.

Occasional clogging occurs in the pumps and the hose connections of the washers, and these may have to be dismantled for cleaning.

Occasionally with severe clogging of the baffle tower, it may be necessary to drain off the caustic-soda solution, fill the reservoir with water, and add a gallon or so of weak muriatic or hydrochloric acid to dissolve the crystals and sludge inside the washer. In a very few minutes the carbonates will be dissolved and can be flushed out. The acid is rinsed quickly from the washer. Severe clogging will not occur if proper attention is given to draining off the exhausted charge, and if excessive operation with infrequent solution changes is avoided.

Large storage chambers require operation of both washers more or less continuously. Some operators feel that it is better to operate both washers continuously on more dilute solutions; thus with regular daily change of solution they have a minimum of detail to occupy their attention. The oxygen percentage is maintained between 2 and 3 per cent. In a gastight storage room, full of fruit, it may be necessary to introduce fresh air into the room for a few minutes every other day or so. This can be done either by raising the sliding window in the gastight door or by opening plugs in the suction pipe leading to one of the air washers for short periods. The slight pressure created in the room by this procedure can be equalized by opening the sliding window in the door an inch or so. Only a few minutes' operation of the blower is required to introduce sufficient fresh air; subsequent analysis of the storage air on the following day will guide the operator in how much air to introduce to maintain about 2 per cent oxygen in the storage room. The fruit in the room may be injured and even killed by prolonged oxygen starvation if the percentage of oxygen is permitted to fall below 1 per cent for too long a time.

MAINTENANCE OF THE PROPER TEMPERATURE AND HUMIDITY

As has already been indicated, temperatures should be determined at least once each day. Temperatures can be manipulated through the automatic or manual controls on the expansion valves. These controls must be on the outside of the room. Fluctuations of temperature of one degree F. above and below are quite permissible. If fluctuations are greater than this, they certainly should not persist for long periods. Brief fluctuations of 2 degrees, while not advisable, would probably do no harm.

A humidity of 90 per cent should be maintained at all times. It has already been pointed out that this is particularly important during the loading period because of the drying capacity of the container wood, shredded paper, and condensation on the cooling surfaces. Water vapor may be added to the air during the loading period by use of a humidifier, or water atomizer, or by keeping the floors wet. Some operators have actually sprinkled the fruit, but this practice is a questionable one if the humidity is to remain very high after that time. If the relative humidity has been kept high during the loading period, it is not likely that any more water vapor will be required during the storage period, although it is well to determine the humidity occasionally. If the drip water from the cooling surfaces is allowed to remain in the room, the relative humidity can't drop very much in a gastight room. Some water vapor is added to the atmosphere during the operation of the washer. The caustic soda when mixed with the water generates considerable heat, and steam will pass over into the storage room. This helps maintain a high humidity during the course of the season. As has been pointed out, however, a critical period from the standpoint of humidity maintenance is during the loading period, and if the boxes are extremely dry, it is best to wet them down before they are filled.

A second critical period from the standpoint of relative humidity comes when the room is unsealed in the spring and the temperature is dropped from 40° to 32–36°F. With this temperature drop, a considerable amount of water may be condensed and frozen on the cooling surfaces, and not only the absolute but the relative humidity may drop. The fact that the fruit itself has a higher temperature than the surrounding air for a few days (until fruit temperature reaches room temperature) also induces some water loss. It is therefore extremely important that the relative humidity be kept at 90 per cent or slightly higher during this period.

With 90 per cent relative humidity there may be some mold growth on the crates at the end of the storage season. This is considered less of a disadvantage than fruit shriveling. If an ozone unit is available during the marketing period, it can be used to dry up the mold. The use of 2 or 3 parts per million several hours each day during the marketing period will not only dry up the mold but sweeten the air in the room and destroy any musty odors.

It is a good practice to keep a log book of temperatures, humidity, and atmospheres. The following form has been found to be useful:

Date	Hour	Carbon dioxide (per cent)	Carbon dioxide plus oxygen (per cent)	Oxygen (per cent)	Temperature degrees (F.)	Humidity (per cent)	Hours washer run	Caustic soda used (pounds)
11/6/41	9 a.m.	5.4	8.0	2.6	40	90	10	25

Such a log is useful in recording an accurate history of the treatment of the apples. The "carbon dioxide plus oxygen" value is included because in making the oxygen determination, carbon dioxide has first been removed and the carbon dioxide value is subtracted from the figure of "carbon dioxide plus oxygen" to give the oxygen percentage.

COSTS

Costs of controlled-atmosphere storage vary with size of the chamber, method of making the room gastight, and other factors. An attempt is made below to present approximate costs based on 1940–41 experience. All costs given are those in excess of ordinary cold storage. Interest on both capital and operating costs is included. All capital costs are prorated over a period of five to eight years to obtain bushel costs per season. It is believed that the rooms will remain gastight and that some of the equipment will have a longer life than five to eight years, however. These costs include cost of labor exclusive of that of operating labor.

Capital costs. In these experiments, a 2000-bushel room was made gastight by use of special paint on the plaster and concrete, at a cost of approximately 1.25 cents per bushel per season. A 13,824-bushel room was made gastight by using paint on the walls and floors and aluminum foil on the ceiling, at a cost of 1.2 cents per bushel per season. A 300-bushel room was made gastight by use of sheet metal, at a cost of 2.0 cents per bushel per season. A 2000-bushel room was made gastight in the same way by a commercial operator at 2.0 cents per bushel. If a new storage is being built, aluminum foil can be used both as an insulant and as a gas seal at very little additional cost, since the only extra item would be the caulking of the joints.

An atmospheric scrubber can be made from discarded oil drums by a blacksmith or welder at a cost of $100 to $150. This size would be adequate for about 2000 bushels. One commercial firm is making these washers.

An Orsat apparatus can be bought already assembled for about $46.00, but if bought unassembled and put together in a homemade case with connections of rubber tubing it can be obtained for about half that amount. Chemicals for a season's operation of the Orsat apparatus should not exceed $5 to $10.

Other capital expenses include cost of carbon dioxide for testing leakage, caulking compound, the gastight door, labor, and pipe. It has been estimated that total capital expense is between 2.5 and 3 cents per bushel per season.

Operating expense. Shredded oiled paper (¼ to ⅓ pound per bushel) costs 3 to 3½ cents per bushel per season. For oiled wraps the cost is somewhat more because of the labor of wrapping.

Caustic soda used in the atmospheric washer costs from 3 to 3.5 cents

per pound. About ¾ pound is required for each bushel of fruit stored each season. This means a cost of 2.2 to 2.6 cents per bushel per season.

Power costs have been estimated for the continuous-blower operation, and operation of the washer, at from 1.5 to 2.0 cents per bushel per season.

Total costs. From the experience of five rooms of commercial size it is estimated that total cost per bushel, exclusive of operating labor, in addition to ordinary cold-storage costs is 9.5 to 10.0 cents per season. This is for a storage season of six months. Of course, if the apples are kept another two or three months in ordinary cold storage before sale, this expense would have to be added to total costs. One operator estimated a total cost of 11.3 cents (above cold-storage costs for six months) for an eight-month season, using controlled atmospheres for six months and ordinary cold storage for the last two months.

It may be noted that the storage is operated at 40°F. instead of 32° during the period of controlled atmospheres, and a slight savings might occur here when a comparison is made with refrigeration costs in ordinary cold storage.

ADVANTAGES OF CONTROLLED-ATMOSPHERE STORAGE

The storage life of certain varieties of apples is markedly increased by use of the proper atmosphere and temperature. Several months can be added to the normal storage life of McIntosh, which is normally past its prime condition in ordinary cold storage at 32° in air by March.

A marked residual effect is noted frequently as a result of this treatment. For example, McIntosh apples removed from controlled atmosphere in March and April remain marketable for long periods of time at room temperatures. In other words, not only do apples have a longer storage life, but they remain marketable for much longer periods of time on the market place than do cold-storage apples.

Several varieties of apples are subject to internal disorders such as brown core, or core flush, and internal browning when stored at temperatures as low as 32°F. in cold storage. When stored in controlled atmospheres of the proper proportions of carbon dioxide and oxygen at a temperature of 40°, these troubles can be avoided in McIntosh.

Mold growth is not quite so rapid in controlled-atmosphere storage as in ordinary air storage. However, if the humidity is kept at 90–95 per cent some mold growth may appear on the boxes and walls.

Mice and rats cannot survive in controlled-atmosphere storage, and hence there is no damage to the fruit from this cause.

DISADVANTAGES OF CONTROLLED-ATMOSPHERE STORAGE

Because of the danger of suffocation and also because of loss of the required atmospheres in the chamber, the storage operator cannot enter the storage room until the room is unsealed. Fruit must be inspected through a window in the door. By using an oxygen mask the operator could go into the room, but opening of the door causes a considerable loss of the atmosphere.

This method of storage is ordinarily used only for fruit that is to be marketed after cold-storage fruit would be past its prime. This means that the storage operator must operate both cold-storage and controlled-atmosphere

rooms if he is to sell apples from harvest time through June or later. When a variety such as McIntosh is stored in controlled atmospheres, the room can be opened in March or April and ordinary cold storage used in the room thereafter during the marketing period.

Fruit of markedly different degrees of maturity, whether of the same variety or different varieties cannot be stored together in the same room.

Judging from the experimental work done to date on the subject, different varieties cannot be stored in the same room. Some varieties at least tend to ripen or cause scald in other varieties when they are stored in the same chamber. For example, Wealthy developed scald when stored with McIntosh.

The rooms must be gastight. If they are not, the venture is likely to fail.

The hazard of storage scald is increased in controlled-atmosphere storage. Scald is caused by accumulations of certain volatiles produced by the fruit itself. In a gastight room there is little flushing away of these gases, and hence scald tends to be accentuated. McIntosh, which is ordinarily not classed as a scald-susceptible variety, will scald in controlled-atmosphere storage unless precautions are taken.

PRECAUTIONS

1. The fruit must be of the proper degree of maturity. If it is too immature, it is likely to scald and to be of low quality. If it is too mature, it does not keep as well.
2. Precautions must be taken for scald control.
3. The rooms should be filled with fruit for best results.
4. The rooms must be gastight. If there is any question about this factor, leakage tests should be conducted.
5. The temperature should be maintained at 40°F. with fluctuations preferably not exceeding 1 degree above or below this temperature.
6. The relative humidity should be kept at 90 per cent. It is particularly important to keep the relative humidity very high during the loading period so that the containers can quickly come to equilibrium with the water vapor in the air. Unless the refrigerant is very cold, special precautions for maintaining humidity do not seem necessary after the rooms are sealed. It should be checked periodically, however, especially when the temperature is dropped after opening the sealed room.
7. The atmosphere should be maintained at 5 per cent carbon dioxide and 2 per cent oxygen, for best results. A range of from 4 to 6 per cent in carbon dioxide is allowable. The oxygen figure should not drop below 1 per cent at any time. Daily measurements of these constituents should be made.
8. There should be a circulation of the atmosphere around the chamber. More or less continuous use of fans seems necessary.
9. Preliminary studies indicate that different varieties should not be stored together.
10. The only variety, in trials to date, that seems to justify this practice is McIntosh. Other varieties which respond, but not so remarkably as McIntosh, are Northwestern Greening, Twenty Ounce, Delicious, Rome Beauty, and Northern Spy.
11. Once the rooms have been closed for a time they should not be entered

without first airing the room. If entrance is attempted, an oxygen mask or some other special precaution should be taken.

12. The sodium-hydroxide solution is caustic and one should be careful to keep it away from open wounds and cuts in the hands. Rubber gloves should be worn.
13. The room should be well aired before any fruit is sold, to remove odors.

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